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SURGICAL HISTORY

From flint to stainless steel: observations on surgical instrument composition

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Man's failure to extract deeply embedded thorns and arrowheads, with bare hands and teeth, stimulated 'instrument substitutes' mimicking these appendages. Evidence from primitive communities suggest animal, plant and mineral items were employed, both before and after metal became the standard material of today's armamentarium. Changing surgical instrument composition has mirrored concurrent technology and manufacturing methods both of which are reviewed. Particular significance is accorded flint, bronze, crucible steel, thermal sterilisation, nickel-plate, stainless steel and disposable plastics. The paper is based on an exhibition *From Flint to Stainless Steel* on display at the College.

> . . . during the Mycenaean period iron was as costly as gold, but from the 10th century BC it was more generally smelted and gradually became common.
>
> *Charles Singer et al. (1)*

Today surgical instruments are manufactured in response to surgical needs perceived by surgeons, interpreted by bioengineers, refined by instrument makers and adjusted to constraints imposed by the materials available, their cost and methods of fabrication. If in the remote past this chain of command was less evident, an instrument's composition and efficiency reflected existent materials whose history warrants closer analysis.

Surgery, derived from the Greek '*cheir-ourgos*' meaning 'hand-work' emphasises the significance of the hand in that branch of medicine responsible for the external manifestations of injury and disease. Surmise suggests that during prehistoric times, the hands and teeth were applied to clean and bind wounds, straighten fractures, reduce dislocations and to extract embedded arrows, conferring on these appendages a surgical role, later to be extended by wood, bone, shell and stone substitutes, that is 'instruments'. Man's digits (albeit in a rubber glove) still retain functions as tactile probes, dilators, hooks, retractors and tweezers, although the hands are also the prime manipulators of analogous metallic and plastic derivatives as well as more complex instruments. In brief, the hand is precursor-in-chief, leader and principal conductor of the surgical instrument orchestra. In the past, a flint or metal knife used as a weapon, for carving domestic implements or for butchering meat, was one and the same thing and if applied to divide the umbilical cord, scarify skin or lance a vein, these were intermittent and non-specific roles. By Graeco-Roman times, however, the specificity of surgical instruments was in evidence and ultimately became complete.

In general, the materials employed have been determined by technological achievements and manufacturing processes remote from the field of surgery. By examining the changing composition of instruments through the ages, it is believed a coherent evolutionary picture of the armamentarium emerges. To emphasise this an exhibition has been arranged titled *From Flint to Stainless Steel*, which condenses many of these changes by utilising instruments ancient and modern in the College collection, animal, vegetable and mineral artefacts, diagrams and photographs (see Appendix). It is hoped that the display will stimulate students and surgeons, and will find a permanent place in the College.

A retrospect of materials should interest all surgeons, not just to assess the evolution of their armamentarium but to assist their choice of instruments, sutures and implants. For example, a knowledge of plastics is important to vascular surgeons and knowledge of steels and non-ferrous alloys is necessary for orthopaedic surgeons.

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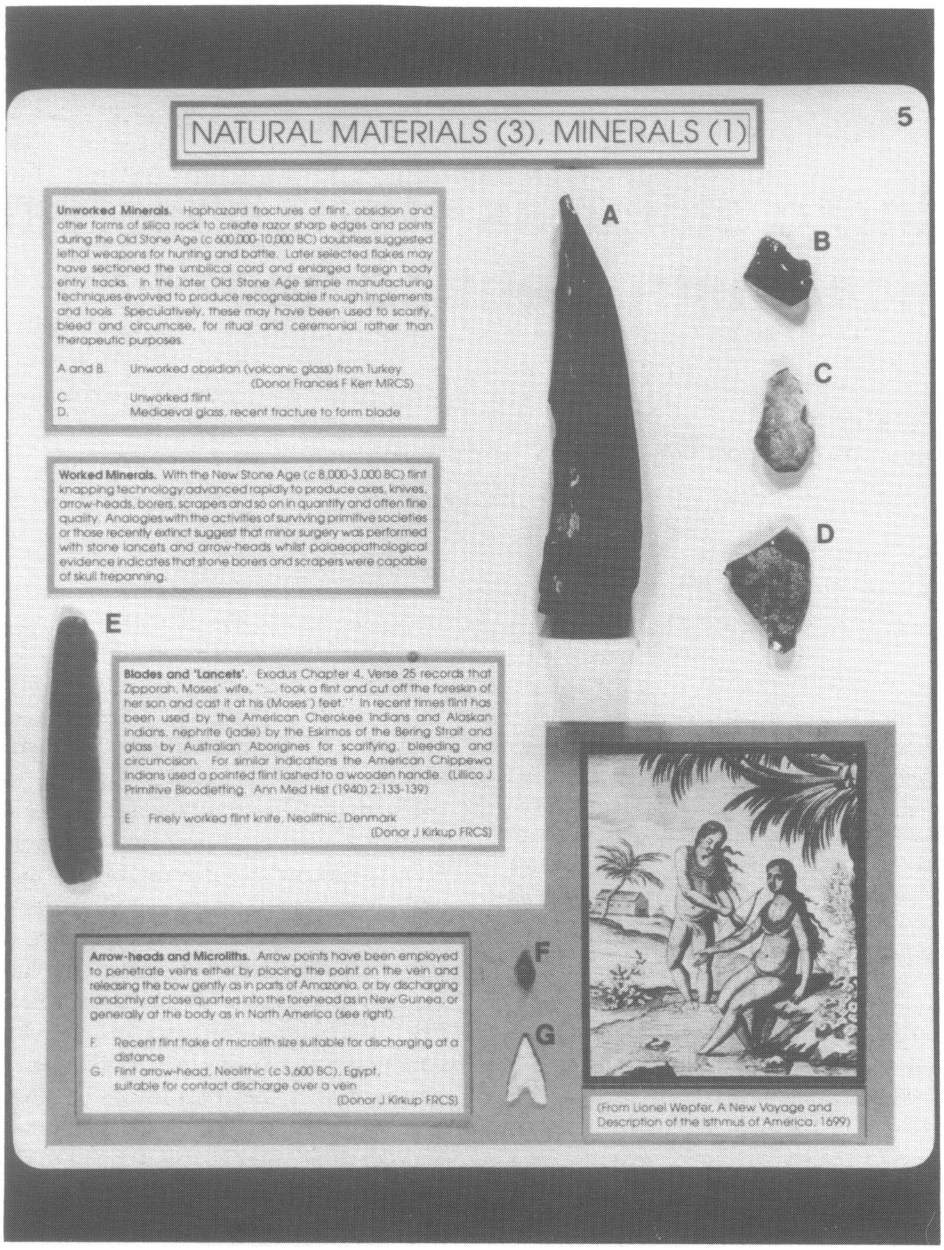

Figure 1. Board 5. Natural materials (3). Flint, obsidian (volcanic glass) and manufactured glass. (With permission of the President and Council of the College.)

Prehistoric possibilities (Boards 1–6)

The origin and nature of rudimentary surgical activity in the prehistoric era cannot be delineated precisely although conjecture is possible, based on our own experiences and those of primitive communities still surviving or recently extinct. If Old Stone Age men or women (*c* 600 000–10 000 BC) divided the umbilical cord and perhaps circumcised both sexes, from time to time, they were daily tested by injury in the struggle to survive a harsh and competitive environment. Hunting animals, fighting other tribes and coping with the accidents of domestic life surely posed perplexing complications such as pain, disability and lingering death which finally provoked attempted solutions. Thus, it is probable that a thorn or twig embedded in the hand or the foot stimulated actions familiar to us all, in the automatic sucking or squeezing of tissues to extract a painful and potential threat to future well-being. Failure to remove a foreign body solely by human appendages ultimately generated more efficient substitutes, beginning with organic 'instruments' found at random or close at hand. Thus, the removal of a thorn was probably attempted with another thorn or a sharpened stick, until bone or antler needles were manufactured some 20 000 years ago *(2)*. Even so, an appropriate thorn was probably more efficient until around 3500 BC when copper or bronze needles became possibilities during the early Metal Age in the Middle East. Larger and deeper foreign bodies such as broken arrows, spears and other missiles, required a more complex approach for, if the fingers did not succeed, then probes of stick or bone allied to enlarged incisions by flint, shell or bamboo knives were likely developments to aid extraction.

That organic items have played a role in solving surgical problems is evident from classical authors and observations made in non-industrialised societies, by explorers and others, especially in the last century. To illustrate animal and vegetable items (Boards 3 and 4), attention is drawn to: a mounted shark tooth used as an abscess opener in the Ellice Islands *(3)*; the perforator-cannula derived from a metacarpal bone of the 'flying-fox' bat (wing-span 1.5 m) employed to tap hydroceles in Fiji *(4)*; the bamboo bougies associated with incision of the penile urethra used for counter-irritant treatment of pneumonia, bronchitis and lumbago also in Fiji *(4)*; the use of a garlic stem by Hippocrates and of a pig's bristle by Paulus of Aegina to probe fistulas *(5,6)*; and to a modern wooden mouth wedge, still available for purchase, and employed in children's anaesthesia.

It is possible that flint, obsidian and other silica-bearing rocks (Boards 5 and 6) (Fig. 1) were used in the Old Stone Age for scarifying, bleeding and circumcision, although their rationale was probably more ritual and ceremonial than therapeutic. During the New Stone Age (*c* 8000–3000 BC) flint technology advanced rapidly to produce axes, knives, arrowheads, borers and scrapers of outstanding refinement *(7)*. Nonetheless, it is doubtful whether any of these were made with a purely surgical objective in view. In recent times flint has been employed by the American Cherokee and Alaskan Indians, nephrite (jade) by the Eskimos of the Bering Strait and glass by Australian Aborigines, for scarifying, bleeding and circumcision *(8)*.

Since the discovery of prehistoric trepanned skulls in 1868, experiments by Lucas-Championierre and others confirm that the adult skull can be trepanned with flint in 35 min *(9)*. If the indications remain obscure, it was a widespread practice and analysis of flint trepanation suggests at least three methods of entry, utilising three different 'instruments'. A scraper to bore a hole after the manner of a trephine, a point to penetrate by drill-like action and link many small holes in order to remove a large disc, and a blade to incise in noughts and crosses fashion to remove a square of bone.

The non-ferrous metal revolution (Boards 7–9)

The utilisation of minor quantities of pure gold, silver and copper, found in alluvial deposits or other native forms, preceded the major technological advance opened up by the discovery of copper ore smelting between 4000 and 3500 BC *(10)*. It is unlikely that this, or the production of copper alloyed to tin (5–15%) to create the much harder bronze about 3500 BC *(11)*, resulted in immediate application to surgical instrument manufacture. It is believed that metal jewellery, weapons, craft tools and domestic implements appeared, possibly in that order, and that items from each of these groups were employed haphazardly for surgical problems as emergencies demanded.

Silver (Board 7) has been utilised continuously for the last 2000 years, for probes, sounds, catheters, directors, tracheostomy tubes and cannulas as it is malleable and relatively corrosion resistant. When the Elkington brothers discovered the electroplating silver process in 1840 *(12)*, silver instruments increased in numbers. Today, solid and plated silver probes and other minor items are still used. Gold, lead and pewter (Board 8) have played lesser roles in the armamentarium. Being inert, gold was recommended by Hippocrates for wiring jaw fractures *(13)*. According to Albucasis, gold cauteries were better than iron but had an unfortunate habit of melting unless the practitioner was diligent *(14)*. Apocryphal tales tell that gold-plated suture needles were reserved for private patients! Lead mallets and Moynihan's pewter gallstone scoops may still be used.

At first sight copper and brass (Board 9) (Fig. 2), an alloy of copper and zinc, appear rare materials and yet frequently they form the core metal on which silver or chromium plate is applied today, particularly for malleable probes, various tubular items and for the hollow handles of retractors, raspatories and other instruments. In ancient Egypt, copper spring forceps may have fulfilled minor surgical roles *(15)* but were soon displaced by bronze substitutes. No purely copper instruments have been traced before a Bengali ophthalmic surgical set of the 19th century, exhibited in the College. In the 20th century, Walton introduced highly polished copper abdominal and brain retractors, pointing out that if sufficiently well finished copper did not require plating; these were still on sale in 1982. Two brass-handled scalpels were excavated at Pompeii *(16)*, but brass is rarely noted otherwise until the 18th century when it was used for intricate items such as screw tourniquets, multi-bladed scarificators and syringes. Traditionally, lancets and other folding items had brass pivots, and the organic handles of scalpels and many other instruments were riveted with brass, until thermal sterilisation revolutionised the armamentarium at the end of the 19th century.

Bronze and Graeco-Roman surgery (Board 10)

Bronze finds from the 6th century BC, at Epidaurus and other ancient healing sites, probably had medical if not surgical connotations. Bronze surgical instruments noted in the Hippocratic writings, of the 4th century BC, are unaccompanied by drawings and probably resemble those found in proven medical or surgical dwellings at Pompeii, buried in AD 97. Other hoards of bronze instruments in good condition are known, particularly of the later Western Roman Empire *(17)*, and demonstrate that bronze has significant resistance against corrosion unlike iron or steel. The Roman use of ferrous metals, for blades, for cauteries and for dental extraction forceps is associated with infrequent archaeological survival, usually severely corroded. Thus many bronze scalpel handles are found with empty sockets or a trace of rust

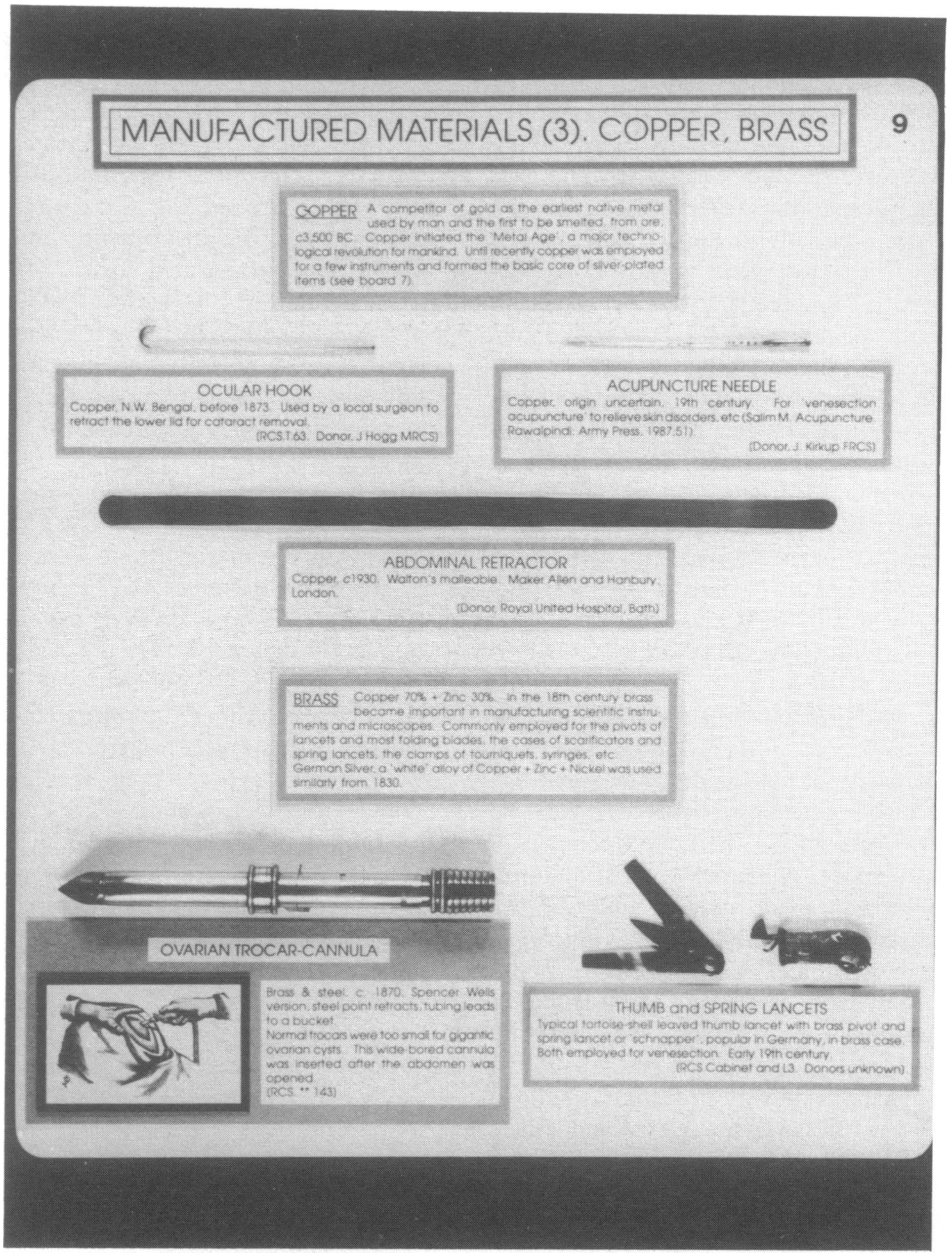

Figure 2. Board 9. Manufactured materials (3). Copper and brass. (With permission of the President and Council of the College.)

and very few with convincing blades. The bronze survivals show Roman surgeons possessed a comprehensive armamentarium, utilising the seven fundamental instrument designs which persist today *(18)* and, possibly, go back as far as the Hippocratic period. Bronze continued in use until the 4th or 5th centuries AD, when it disappears from archaeological finds. Sadly, Roman items owned by the College, including bronze facsimiles of Pompeiian instruments, were destroyed by bomb damage in 1941.

Iron and steel (Boards 11 and 12)

Wrought iron, discovered in Armenia *c* 1900–1400 BC, was slow to evolve owing to delay in realising that smelted ore needed heating and hammering repeatedly to separate metal from slag *(19)*. Ultimately this generated almost pure iron which does not take a cutting edge; it is unlikely wrought iron was employed extensively in surgical practice (Fig. 3).

Heating with charcoal was found to harden the surface layer and provide a steel facing capable of being sharpened to a keen blade. Invented by the Chalybes of Asia Minor *c* 1400–1200 BC *(20)*, the steeling of iron vastly improved the quality of weapons, tools and implements and gradually superseded bronze. Steel and bronze coexisted until the end of the Roman Western Empire, when bronze disappeared and it is assumed that steel became the universal metal. However, little archaeological evidence of steel instruments has come to light and this, taken with the relatively few surviving written accounts of surgery, creates a 'dark age' of instrumentation, virtually until the Renaissance.

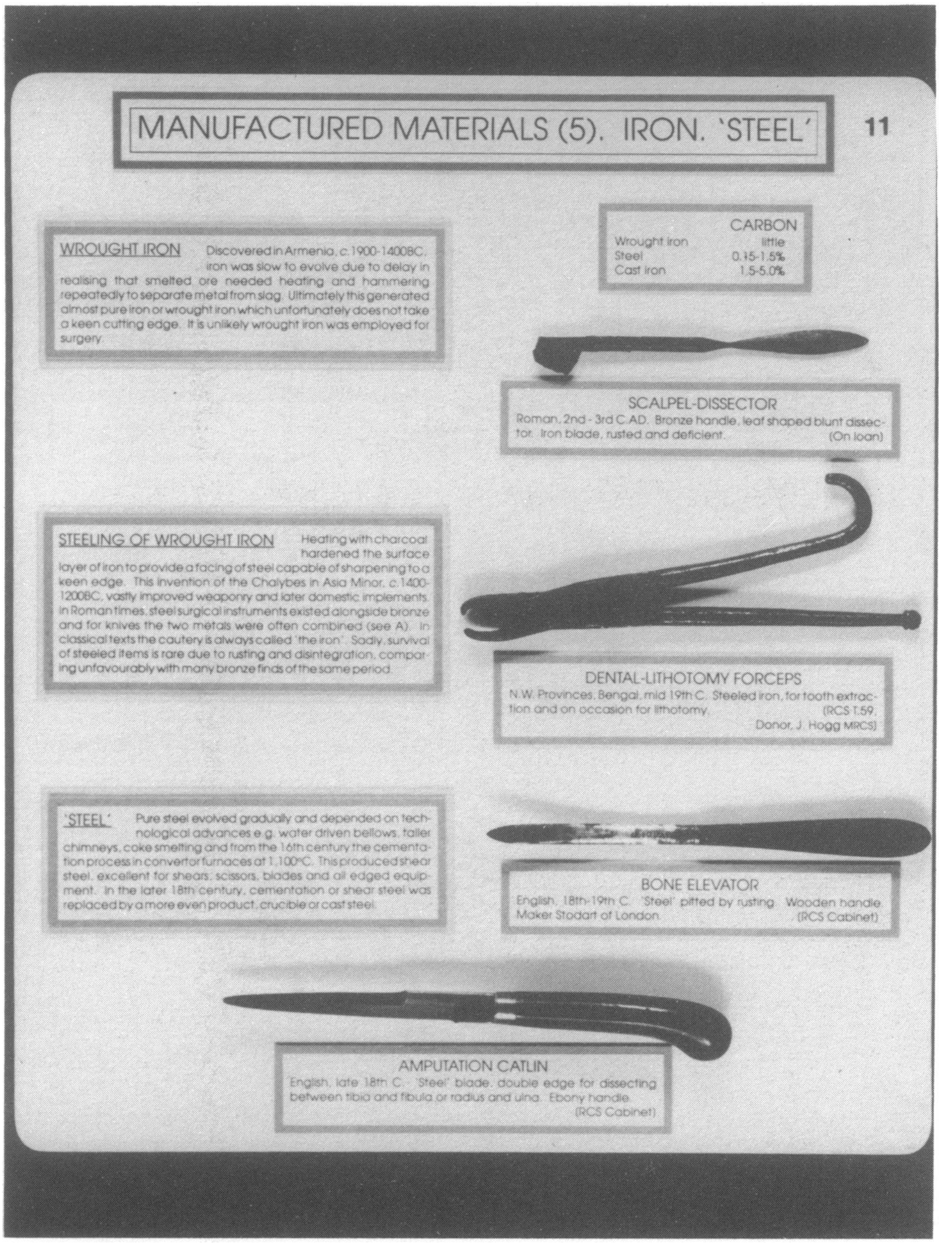

Figure 3. Board 11. Manufactured materials (5). Wrought iron and steelified iron. (With permission of the President and Council of the College.)

Improved steel evolved gradually in relation to technological advances such as water-driven bellows and tall chimneys to generate increased draught and coke smelting needed for the higher temperatures of the blast furnace from the 16th century. This produced shear steel, generally good for shears, scissors, blades and all edged equipment, but of uneven quality and liable to breakage. In the 18th century shear steel was improved by the introduction of commercial crucible or cast steel, a more homogeneous product.

Established by Huntsman in Sheffield about 1750 *(21)*, the new steel was produced by refining shear steel at 1600°C in ceramic crucibles, then poured or cast into ingot moulds. This finer steel provided lighter and more reliable instruments, transforming cumbersome amputation knives into elegant lance blades and heavy-framed bow saws into tenon saws. By the late 18th century, crucible steel was the basic metal of surgical instrumentation and remained so until stainless steel was introduced in the 1920s. The finest hand-forged and finished crucible steel is often spotless after 150 years and certainly sharper than stainless steel, for which reason carbon steel, a similar product to crucible steel, is the material of choice for the detachable and disposable scalpel blades of modern surgery. Nevertheless if exposed to moisture such steels will rust.

Elegant instruments and their demise
(Board 16)

Some Roman instruments are finished with minor decorative features and occasionally with silver ornamentation

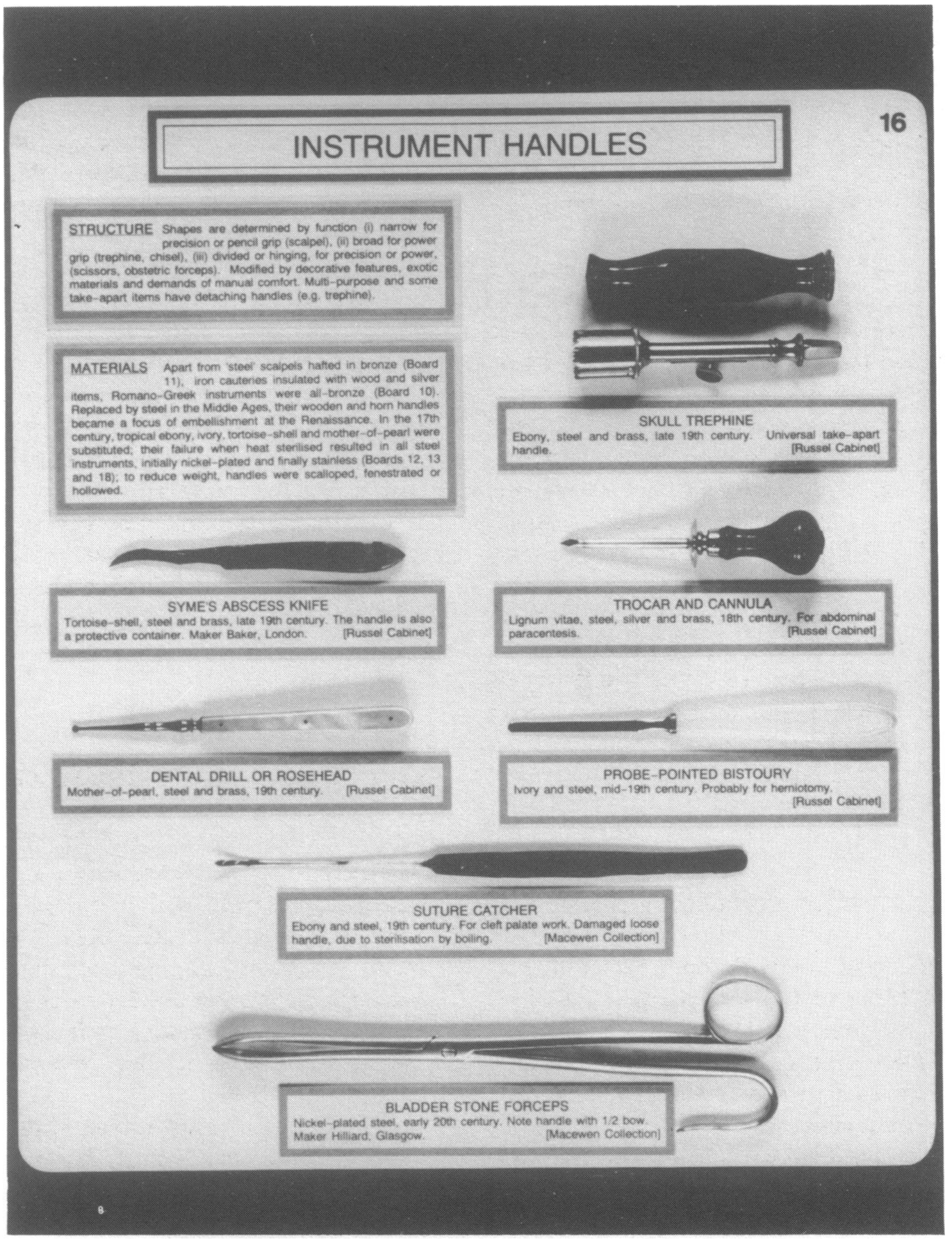

Figure 4. Board 16. Instrument handles. (With permission of the President and Council of the College.)

inlaid into the bronze or, rarely, onlay silver spiral decoration. However, until the 18th century most instruments remained functional, or carried at most restrained carving of bone, horn or wooden handles. With the expansion of Western European overseas trade in the 17th century, and perhaps rising fortunes of the merchant class and their surgical advisers, exotic materials including tortoiseshell, ivory, mother-of-pearl, lignum vitae, ebony and other fine woods became available to instrument makers. Throughout the 18th and 19th centuries, instrument handles were manufactured in these materials (Board 16) (Fig. 4), except where this was technically inappropriate. One paid according to one's purse, for ivory and pearl were more expensive than ebony which, for some, might prove to be a local hard wood suitably stained. These elegant instruments are much sought by collectors and constitute the focus of antique dealers' attention in the surgical instrument field. With the acceptance of antiseptic surgery and then heat sterilisation, introduced between 1883 and 1893, ornamental organic handles warped and disintegrated, and steel corrosion was accelerated, causing a crisis for those adopting aseptic techniques. As a matter of urgency, all-metal instruments were manufactured and steel was protected by nickel or chrome plate.

Nickel and chrome plate (Board 12)

Heat sterilisation of instruments and equipment inspired surgical endeavour in astonishing fashion, as safe exploration of the body cavities, skull, spine and joints suddenly became a reality. In turn, this stimulated a demand for new instruments on an unprecedented scale, to be met by increasing ingenuity by instrument makers, as demonstrated in their rapidly enlarging and numerous instrument catalogues *(22)*. By the early years of the 20th century, even the sternest critic of new methods had accepted this major surgical and instrument revolution. Concurrently, enamelled and plated equipment became the rule, nickel being generally applied in Europe and to some degree in North America where chrome was also popular. Nickel plate had its limitations, dependent on the quality, although even the best was liable to peel or flake at the pivot joint of scissors and haemostatic forceps leading to rust of the underlying steel. For this reason 'take-off' joints became popular so that instruments could be taken apart to facilitate cleaning of the pivot area of blood, debris and rust *(23)*. However, in busy operating theatres the two halves of instruments often became separated and, as no pairs were exactly identical being hand-made, attempts to match produced breakages of connecting pivots and general frustration. In Britain at least, the permanent screw joint was accepted as more practical and certainly cheaper than the sophisticated 'take-off' or dismountable joint.

Stainless and high alloy steels (Board 13)

Early steels were alloys of iron with minute quantities of carbon, between 0.15% and 1.50%, although other contaminants might be present. During the late 19th century, harder steels were made with alloys of chromium, tungsten, manganese and nickel *(24)*. Stainless steel, resistant to corrosion, was introduced commercially by Brearley of Sheffield in 1912 for the rifling of gun barrels. This contained 13% chromium, 1% nickel and 0.2% carbon, now classified as a 'low' alloy stainless steel. Recommended by Brearley for domestic cutlery, it was employed by Mayer and Company in 1916 on behalf of the otolaryngologist Heath of London, who appears to be the first to use non-rusting steel instruments *(25)*. In 1925, many instrument catalogues offered stainless steel as a more expensive alternative to nickel-plated steel instruments and, by 1938, many makers had abandoned plating entirely. Despite corrosion resistance, strength, and suitability for thermal hardening and tempering, stainless steel furnishes a poor cutting edge and needs constant sharpening. Scalpel blades, chisels, gouges and other edged instruments often continue to be made of carbon steels which, though very sharp, will rust.

Despite the excellent resistance of 'low' alloy stainless steel when in temporary contact with human and other fluids, implants left in the body, especially fracture plates and screws, were found to corrode *(26)*. This promoted 'high' alloy or Martensitic and Austenitic steels with 17% to 18% chrome, 3% to 14% nickel and sometimes molybdenum, which proved extremely inert in the body, (Fig. 5).

Miscellaneous metals (Board 14)

Aluminium, which lacks hardness and durability, has been used for simple instruments where its lightness may be an advantage, such as aural, laryngeal and uterine probes and also uterine dilators. An alloy, 'duralumin', maintains good balance for the solid handles of osteotomes and gouges, and is resistant enough to be struck with a mallet.

Platinum, despite its expense, was employed formerly for the diathermy and cutting points of electrocautery equipment.

Titanium, another light metal, is used today for the handles of ophthalmic, microsurgical and other fine instruments. It is inert in human tissues and suitable for bone and other implants.

Tantalum is implanted as a mesh and as suture wire. Alloys of cobalt, chromium and molybdenum are strong, inert and popular as dental and orthopaedic implants.

Gum elastic, rubber, plastics and disposability (Board 15)

Attempts to make malleable non-metallic catheters produced horn and leather tubes and spirals of silver wire covered with animal skin, but all proved objectionable owing to contamination and putrefaction. In 1779, Bernard of Paris painted layers of plant gum onto a silk tubular scaffold to make a gum elastic catheter *(27)*; this material remained in the armamentarium long after rubber was introduced.

By softening natural rubber with volatile oil in 1791, Grossart made the first rubber tubing specifically for surgical use *(28)*, but this deteriorated with variations of temperature. Further research by Goodyear of Philadelphia discovered a stable rubber by vulcanisation with sulphur in 1841 *(29)*. Its subsequent application in surgery, like gum elastic, has been superseded by plastics.

The discovery of celluloid in 1869 and bakelite in 1907, was followed by the first true plastics, polymers of synthetic resins, in the 1920s.

After nylon established a role as suture material, acrylic resin femoral heads *(30)* and Teflon® acetabular cups *(31)* proved implant failures. Since then, high-density polyethylene joint prostheses, methyl methacrylate bone-cement, terylene-dacron arterial prostheses and Silastic® substitutes have succeeded as implant materials. Meanwhile, plastic catheters, tubing, syringes, needle mounts, dressing forceps, arterial forceps, suture material, speculi, proctoscopes and other items all end brief lives in an incinerator, as agents of a 'disposable revolution', and laser, ultrasound and lithotriptor surgery diminish the need for traditional instruments. Will minimal access surgery emasculate still further the 20th century armamentarium?

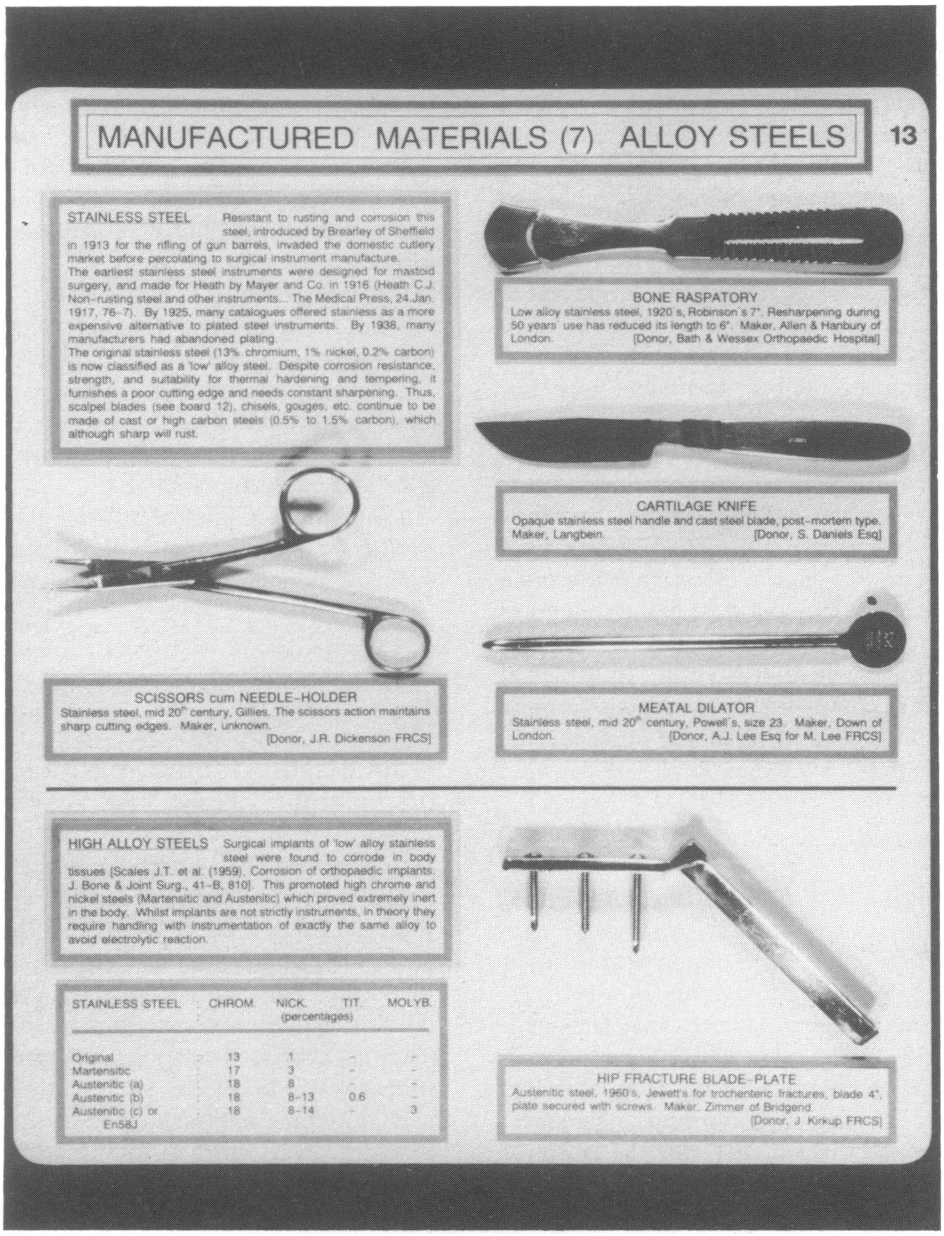

Figure 5. Board 13. Manufactured materials (7). Stainless and high alloy steels. (With permission of the President and Council of the College.)

Metal manufacture and instrument makers
(Board 17)

Copper and bronze instruments are cast and forged at low temperatures producing uniform products, unlike steels which require high temperatures and vary widely in quality, dependent on their exact composition and tempering. Until this century, all steel instruments were forged and tempered from bar material by hand. Today drop-forging, punching, nibbling and laser-cutting contribute an element of mechanisation, yet much hand work continues to fit and finish the best and finest instruments.

For centuries, surgeons depended on a medley of specialists including cutlers, razor-makers, blacksmiths, silversmiths, goldsmiths, wire-drawers, needle-makers and also pewter, brass, tortoiseshell, ivory, pearl and wood artisans. In the late 18th century, a few cutlers concentrated on surgical instruments exclusively and companies such as Weiss of London and Young of Edinburgh (both still in business) aimed to supply most items.

Instrument firms have appeared, disappeared or amalgamated continuously. Important 19th century names include Savigny, Arnold and Down of London, Charriere, Collin and Mathieu of Paris, Jetter and Scheerer of Tuttlingen, Stille of Stockholm, Tiemann of New York and Truax of Chicago. Instrument makers' catalogues, first published in the late 18th century, remain the key to identifying particular instruments. Unfortunately, many catalogues have not survived and even a combination of worldwide resources may fail to achieve instrument recognition.

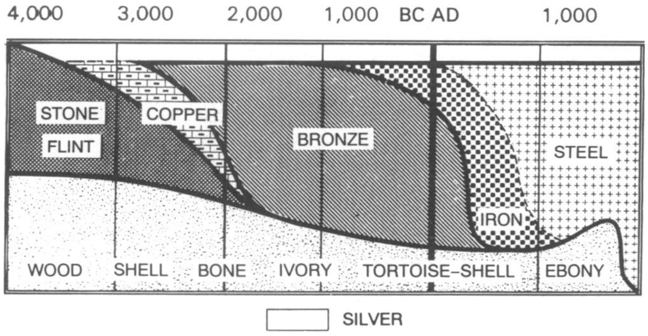

Figure 6. Instrument materials (*c* 4000 BC–AD 2000).

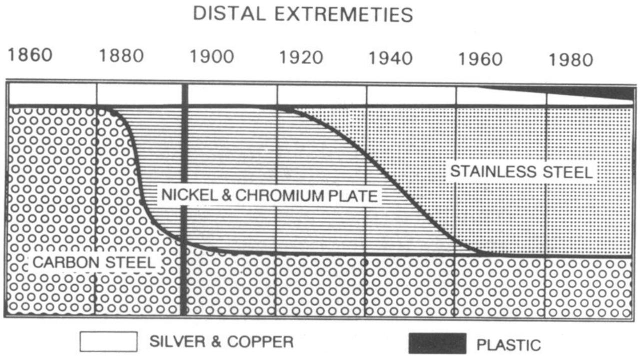

Figure 7. Distal instrument extremities (AD 1860–2000).

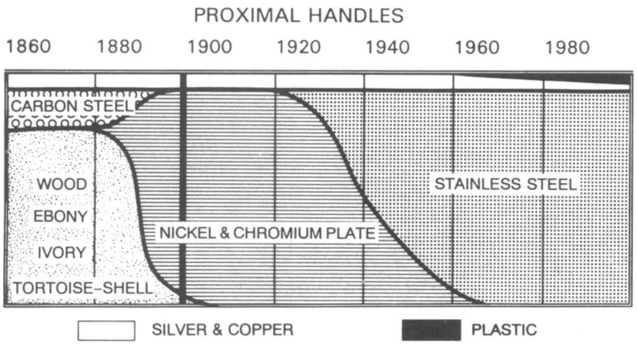

Figure 8. Proximal instrument handles (AD 1860–2000).

Materials overview (Board 18)

In analysing the main advances and factors contributing to the composition of surgical instruments over several thousand years, much has been omitted and doubtless much overlooked. If initial instrument forms and materials were non-specific to surgical needs, eventually surgeons posed precise problems to instrument makers, and latterly to bioengineers, in anticipation of specific solutions. Nonetheless, these solutions depended on the materials available and overall have correlated with technological progress.

To demonstrate an overview of these changes since the Metal Age, Fig. 6 shows the principal organic and inorganic materials available to fabricate weapons, tools, domestic utensils and hence surgical instruments. Figure 7 indicates how the material composition of the working extremity of instruments responded to both surgical ideas and to available technology, particularly the introduction of thermal sterilisation and stainless steel. Figure 8 indicates the different response of the handle to the same factors.

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Appendix

From Flint to Stainless Steel

(Titles of Boards exhibited in The Royal College of Surgeons of England)

Board
1. Introduction
2. Origins
3. Natural Materials (1) Animal
4. Natural Materials (2) Vegetable
5. Natural Materials (3) Minerals (1)
6. Natural Materials (4) Minerals (2).
7. Manufactured Materials (1) Silver
8. Manufactured Materials (2) Gold, Pewter
9. Manufactured Materials (3) Copper, Brass
10. Manufactured Materials (4) Bronze
11. Manufactured Materials (5) Iron, 'Steel'
12. Manufactured Materials (6) Cast Steel, Plated Steel
13. Manufactured Materials (7) Alloy Steels
14. Manufactured Materials (8) Other Non-Ferrous Metals
15. Manufactured Materials (9) Rubber and Plastics
16. Instrument Handles
17. Manufacture
18. Materials Overview